



UNIVERSITI PUTRA MALAYSIA

**DEVELOPMENT AND IMPLEMENTATION OF A NOVEL CODE FAMILY
FOR OPTICAL CODE DIVISION MULTIPLE ACCESS SYSTEM**

SYED ALWEE AL-JUNID BIN SYED JUNID.

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**DEVELOPMENT AND IMPLEMENTATION OF A NOVEL CODE FAMILY
FOR OPTICAL CODE DIVISION MULTIPLE ACCESS SYSTEMS**

By

SYED ALWEE ALJUNID BIN SYED JUNID

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in
Fulfilment of Requirements for the Degree of Doctor of Philosophy**

July 2005



To My Beloved Wife and Son

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Doctor of Philosophy

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Chairman: Associate Professor Mohamad Khazani Abdullah, PhD

Faculty: Engineering

Future telecommunication systems and networks are expected to provide a variety of integrated broadband services to the customers. There has been a tremendous interest in applying Code Division Multiple Access (CDMA) techniques to fiber optic communication systems. This technique is one of the multiple access schemes that is becoming popular because of the flexibility in the allocation of channels, ability to operate asynchronously, enhanced privacy and increased capacity in bursty networks.

The performance of any Optical CDMA (OCDMA) system strongly depends on the codes properties. In this study we introduce a new code for Optical CDMA namely Double Weight Code family (DW). Double Weight Code (DW) has a basic fixed weight of 2 and exists for every natural number. The DW codes possess ideal cross correlation properties, which have important characteristics in OCDMA systems since these can eliminate multiple access interference (MAI) and reduce noise. Also proposed in this

study, a Modified Double-Weight (MDW) code, which is a variation of DW code family that can have a variable weight greater than two. The MDW code possesses ideal cross-correlation properties and exists for every natural number too. It is shown through simulations, theoretical analysis and partially by the experiments that the transmission performance of DW code family is significantly better than that of existing codes such as Modified Frequency Hopping code (MFH) and Hadamard code.

The performance of DW code family, MFH and Hadamard codes were simulated using commercial simulation software, OptiSystem Version 3.0. The performance of the systems was characterized by referring to the bit error rate (BER) and the eye patterns. DW code family has shown superior performance compared to other OCDMA codes. The simulated eye pattern of one of the four MDW coded carriers running at 10Gbps over a communication-standard fiber shows a good quality transmission at the BER of 10^{-12} as opposed to only 10^{-3} and 10^{-4} for Hadamard and MFH codes.

In optical CDMA systems, the detection process affects the design of transmitters and receivers. Cross-correlation functions are generated which creates Multiple Access Interference (MAI) and this will degrade the system performance. MAI can be reduced by using subtraction techniques. The most common subtraction technique is the complementary subtraction technique and also known as balanced detection technique. In this thesis, we also introduce a new approach called AND subtraction technique. This method rejects unwanted signals that interfere with the original signals. Furthermore, the purpose of this new subtraction technique is to reduce the receiver complexity and increase system performance. It has been shown through theoretical analysis, simulation

and experimental work, the performance of the system with AND subtraction technique can be improved significantly. Based on the theoretical analysis, BER as good as 10^{-12} is achieved at the bit rate of 622 Mbps over 70 km distance.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PEMBANGUNAN DAN PELAKSANAAN NOVEL KOD FAMILI UNTUK
SISTEM OPTIKAL CAPAIAN PELBAGAI PEMBAHAGIAN KOD**

Oleh

SYED ALWEE ALJUNID BIN SYED JUNID

Julai 2005

Pengerusi: Profesor Madya Mohamad Khazani Abdullah, PhD

Fakulti: Kejuruteraan

Sistem telekomunikasi dan rangkaian masa hadapan dijangkakan dapat menyediakan pelbagai perkhidmatan jalur lebar bersepadu kepada pelanggan. Dilaporkan terdapat minat yang mendalam untuk mengaplikasikan teknik capaian pelbagai pembahagian kod (CDMA) di dalam sistem komunikasi gentian optik. Teknik ini adalah salah satu skema pemultipleksan yang popular sejak akhir-akhir ini di kalangan penyelidik oleh kerana pembahagian saluran yang anjal, berupaya berfungsi secara tak segerak, peningkatan dari segi keselamatan dan juga kapasiti dalam rangkaian yang bersifat letusan.

Prestasi sebarang sistem CDMA sangat bergantung kepada ciri-ciri kod. Dalam tesis ini telah diperkenalkan satu kod baru untuk CDMA optik yang dinamakan keluarga kod Dwi Pemberat (DW). Kod DW mempunyai pemberat asas ditetapkan kepada dua dan wujud dalam setiap nombor biasa. Kod DW ini mempunyai sifat-sifat sekatan bersilang yang unggul yang merupakan ciri yang penting dalam sistem OCDMA memandangkan ia dapat menghapuskan gangguan capaian pelbagai (MAI) dan mengurangkan hingar.

Turut dicadangkan di dalam tesis ini ialah kod Dwi Pemberat Diubahsuai (MDW), yang merupakan satu variasi yang lain dalam keluarga kod Dwi Pemberat yang mempunyai pemberat bolehubah lebih besar daripada dua. MDW juga mempunyai sifat-sifat sekatan bersilang yang unggul dan wujud dalam setiap nombor biasa. Ia akan ditunjukkan secara prinsip menggunakan simulasi secara komprehensif, analisis teori dan sebahagiannya melalui eksperimen yang menunjukkan bahawa prestasi penghantaran kod Dwi Pemberat adalah lebih baik berbanding kod yang sedia wujud seperti MFH dan Hadamard.

Prestasi keluarga kod Dwi Pemberat, MFH dan Hadamard disimulasikan dengan menggunakan perisian simulasi komersil, OptiSystem versi 3.0. Prestasi sistem diterjemahkan dengan merujuk kepada kadar ralat bit, (BER) dan corak mata. Kod keluarga Dwi pemberat telah berjaya menunjukkan prestasi yang lebih baik berbanding dengan kod OCDMA yang lain. Berdasarkan simulasi, corak mata salah satu daripada empat penghantar isyarat pada kadar 10 Gbps dalam gentian berpiawaian komunikasi menunjukkan kualiti penghantaran yang baik dengan BER pada 10^{-12} berbanding dengan hanya 10^{-3} dan 10^{-4} bagi kod Hadamard dan MFH.

Dalam sistem OCDMA, proses pengesanan memberi kesan terhadap rekabentuk penghantar dan penerima. Fungsi sekatan bersilang akan terjana dan hal ini menyebabkan terjadinya gangguan capaian pelbagai (MAI) dan boleh menyebabkan prestasi sistem itu merosot. MAI boleh dikurangkan dengan menggunakan teknik penolakan. Teknik penolakan yang sering digunakan ialah teknik penolakan pelengkap dan teknik ini juga dikenali sebagai teknik pengesanan terimbang. Di dalam tesis ini,

juga akan diperkenalkan satu pendekatan baru yang dinamakan teknik penolakan AND. Penggunaan kaedah ini bertujuan untuk membuang isyarat yang tidak diinginkan daripada mengganggu isyarat asal. Selain itu, teknik ini juga bertujuan untuk mengurangkan pembinaan rekabentuk penerima yang kompleks dan seterusnya meningkatkan prestasi sistem. Dengan menggunakan teknik penolakan AND ini, prestasi sistem dapat ditingkatkan dengan mendadak dan hal ini telah dibuktikan melalui analisis teori, simulasi dan secara eksperimen. Secara teori, kualiti penghantaran yang baik dengan BER pada 10^{-12} di catatkan pada jarak 70 km pada kelajuan data 622 Mbps.

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I certify that an Examination Committee met on 1st July 2005 to conduct the final examination of Syed Alwee Aljunid bin Syed Junid on his Doctor of Philosophy thesis entitled "Development and Implementation of a Novel Code Family for Optical Code Division Multiple Access Systems" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Zakariah Abdul Rashid, PhD
Professor
School of Graduate Studies
Universiti Putra Malaysia
(Chairman)

Mohd Adzir Mahdi, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Sabira Khatun, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Shahbudin Shaari, PhD
Professor
Faculty of Engineering
Universiti Kebangsaan Malaysia
(External Examiner)


GULAM RUSUL RAHMAT ALI, PhD
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 22 AUG 2005

This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

Mohammad Khazani Abdullah, PhD

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Borhanuddin Mohd Ali, PhD

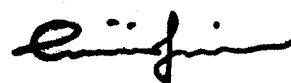
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Abdul Rahman Ramli, PhD

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mahamod Ismail, PhD

Associate Professor
Faculty of Engineering
Universiti Kebangsaan Malaysia
(Member)



AINI IDERIS, PhD

Professor/Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: **08 SEP 2005**

DECLARATION

I hereby declare that the thesis is based on my original work except for the quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or currently submitted for any other degree at UPM or other institutions.



SYED ALWEE ALJUNID BIN SYED JUNID

Date: 6 AUGUST 2005

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	vi
ACKNOWLEDGMENTS	ix
APPROVAL	xi
DECLARATION	xiii
LIST OF TABLES	xviii
LIST OF FIGURES	xix
LIST OF ABBREVIATION	xxiii
CHAPTERS	
1. INTRODUCTION	1.1
1.1 Background	1.1
1.2 Multiple Access Schemes	1.3
1.3 Problem Statement	1.5
1.4 Objectives	1.7
1.5 Scope of Works	1.8
1.6 Methodology	1.10
1.6.1 Simulation Analysis	1.11
1.6.2 Design Parameter	1.12
1.6.2.1 Distance	1.13
1.6.2.2 Bit Rate	1.14
1.6.2.3 Transmit Power	1.14
1.6.2.4 Chip Spacing	1.15
1.6.3 Performance Parameter	1.17
1.6.3.1 Bit Error Rate (BER)	1.17
1.6.3.2 Received Power (Output Power)	1.17
1.6.3.3 Noise Power	1.18
1.7 Thesis Overview	1.18
 2. REVIEW ON MULTIPLEXING AND MULTIPLE ACCESS TECHNOLOGIES	 2.1
2.1 Introduction	2.1
2.2 Multiplexing and Multiple Access Techniques	2.1
2.3 Fiber Optic Multiplexing Methods	2.2
2.3.1 Time Division Multiplexing (TDM)	2.3
2.3.2 Frequency Division Multiplexing (FDM)	2.4
2.3.3 Wavelength Division Multiplexing (WDM)	2.4
2.3.4 Optical CDMA Technology	2.6
2.4 Optical Code Division Multiple Access (OCDMA) Systems	2.9



2.4.1	Optical Code Division Multiple Access Equipments	2.11
2.4.2	Coherent OCDMA Systems	2.12
2.4.2.1	Delayed Line Based Coherent Direct Sequence Optical CDMA	2.12
2.4.2.2	Time Spread Optical CDMA	2.14
2.4.3	Incoherent OCDMA Systems	2.15
2.4.3.1	Incoherent Spectral Intensity Encoded Optical CDMA System	2.16
2.4.3.2	Optical Spectral CDMA (OSCDMA) System	2.18
2.5	Optical CDMA Codes	2.20
2.5.1	Optical Orthogonal Codes (OOC)	2.22
2.5.2	Prime Code	2.24
2.5.3	Modified Frequency Hopping Code (MFH)	2.26
2.5.4	Hadamard Code	2.29
2.6	OCDMA Applications	2.31
2.6.1	Metropolitan Area Network	2.32
2.6.1.1	OCDMA for Metropolitan Area Networks	2.33
2.7	Conclusions	2.35
3.	DEVELOPMENT OF DOUBLE WEIGHT(DW) CODE FAMILY	3.1
3.1	Introduction	3.1
3.2	Optical Code Design Considerations	3.2
3.2.1	DW Code Construction	3.4
3.2.1.1	Properties of DW Code	3.8
3.2.2	Modified Double Weight (MDW) Code Construction	3.9
3.2.2.1	Properties of MDW Code	3.15
3.2.3	Variable Weight Code System	3.16
3.2.3.1	Variable Weight System Implementation	3.19
3.2.4	Process of Encoding/Decoding	3.21
3.3	Code Comparisons	3.22
3.4	Conclusions	3.25
4.	MULTIPLE ACCESS INTERFERENCE, NOISE AND DETECTION SCHEME OF OCDMA SYSTEM	4.1
4.1	Introduction	4.1
4.2	Multiple Access Interference (MAI)	4.1
4.3	Noise Consideration	4.5
4.3.1	Phase Induced Intensity Noise (PIIN)	4.5
4.3.2	Shot Noise	4.7
4.3.3	Thermal Noise	4.8
4.4	OCDMA Detection Scheme	4.10
4.4.1	Complementary Subtraction Technique	4.11
4.4.2	AND Subtraction Technique	4.13
4.5	Optical CDMA Systems Using DW Code Family	4.15
4.5.1	Complementary Subtraction System	4.15
4.5.2	AND Subtraction System	4.25

4.6	Performance Comparison Between Complementary and AND Subtraction Techniques	4.27
4.6.1	Calculated Result	4.27
4.6.1.1	Effect of Number of Users on System Performance	4.27
4.6.1.2	Effect of Received Power P_{sr} on System Performance	4.29
4.6.2	Simulation Result	4.30
4.6.2.1	Effect of Distance on System Performance	4.32
4.6.2.2	Effect of Distance on Noise Power and Output Power	4.33
4.6.2.3	Effect of Input Power on System Performance	4.35
4.6.2.4	Effect of Input Power on Noise Power and Output Power	4.36
4.6.2.5	Effect of Bit Rate on System Performance for Different Subtraction Techniques	4.37
4.7	Conclusions	4.39
5.	THE THEORETICAL PERFORMANCE OF OPTICAL CDMA CODE	5.1
5.1	Introduction	5.1
5.2	Theoretical Performance Analysis	5.1
5.2.1	Relationship Between Received Power and PIIN Noise	5.2
5.2.2	Relationship Between the Number of Active Users (K) and PIIN Noise	5.4
5.2.3	The Effect of Number of Users on System Performance by Considering PIIN Only.	5.5
5.2.4	The Effect of Received Power (P_{sr}) on Shot Noise	5.6
5.2.5	The Effect of P_{sr} on System Performance by Considering Only Shot Noise	5.8
5.2.6	The Effect of P_{sr} on Performance Considering All Noise	5.10
5.2.7	The Theoretical Effect of the Number of Users on the Performance Considering All Noise	5.12
5.3	Code Evaluation and Comparison	5.13
5.3.1	Simulation Result.	5.15
5.4	OCDMA Transmission Design Issues	5.18
5.4.1	Modulation Technique	5.19
5.4.1.1	Effect of Distance on System Performance For Different Modulation Techniques	5.21
5.4.2	Optical Light Sources: Single versus Multiple	5.22
5.4.2.1	Effect of Distance on System Performance for Different Light Sources	5.24
5.4.3	Variable Weight Code System	5.25
5.4.3.1	Performance Analysis of a Variable Weight	5.26

	Code System	
5.4.4	Multiple Bit Rate System	5.29
5.4.4.1	Performance Analysis of Multiple Bit Rate System	5.29
5.5	Conclusions	5.32
6.	APPLICATION OF DOUBLE WEIGHT CODE FAMILIES IN METROPOLITAN AREA NETWORK	6.1
6.1	Introduction	6.1
6.2	Optical Code Division Multiplexing (OCDM) for Metropolitan Area Network	6.1
6.3	Simulation Setup for Point-to-Point Networks	6.2
6.4	Simulation Results for Point-to-Point Network	6.4
6.4.1	The Effect of Distance in Point-to-Point Network	6.5
6.4.1.1	Effect of Distance on System Performance	6.5
6.4.1.2	Effect of Distance on Output Power and Noise Power	6.6
6.4.2	The Effect of Input Power in Point-to-Point Network	6.8
6.4.2.1	Effect of Input Power on System Performance at Bit Rate 2.5Gbps	6.8
6.4.2.2	Effect of Input Power on Output Power and Noise Power	6.9
6.4.3	The Effect of Chip Spacing in Point-to-Point Network	6.10
6.4.3.1	Effect of Chip Spacing on System Performance at Bit Rate 2.5 Gbps	6.10
6.4.4	The Effect of Bit Rate in Point-to-Point Network	6.11
6.4.4.1	The Effect Bit Rate on System Performance	6.12
6.5	Experimental Analysis	6.13
6.5.1	Experimental Setup	6.13
6.5.2	Experiment Results	6.16
6.6	Comparison Between Simulation And Experimental Results	6.20
6.6.1	Comparison Between Theoretical And Experimental Results	6.21
6.6.2	Experimental Results For DW Against Hadamard	6.22
6.7	Conclusions	6.24
7.	CONCLUSIONS AND FUTURE WORK	7.1
7.1	Conclusion	7.1
7.2	Future Works	7.3
	REFERENCES	R1
	APPENDICES	A.1
	BIODATA OF THE AUTHOR	B.1
	PUBLICATIONS	B.2

LIST OF TABLES

Table		Page
1.1	Comparison of Common Optical Multiple Access Schemes.	1.4
1.2	Parameters for Nonlinear Dispersion Shifted Fiber G.652.	1.13
2.1	Comparison Between WDM/DWDM and OCDMA.	2.5
2.2	Example of Required Codeword Length N for a Given Number of User $ C $ and Weight W for an OOC Code Construction.	2.23
2.3	MFH Code Example.	2.29
2.4	Hadamard Code Sequences for 6 Users.	2.31
3.1	Example of DW Code Sequences.	3.6
3.2	Example of MDW ($W = 4$) Code Sequences.	3.14
3.3	Existing Code Weight.	3.20
3.4	Extending the Code Weight.	3.21
3.5	Comparison between MDW, MFH, OOC, Hadamard and Prime Codes for Same Number of User $K = 30$.	3.23
3.6	Comparison Between MDW, MFH And Hadamard Codes.	3.24
4.1	Example of Complementary and AND Subtraction Techniques.	4.14
4.2	Symbols and Parameters for the Setup in Figure 4.2.	4.17
4.3	Typical Parameters Used in the Calculation.	4.28
5.1	Values of P for Various OCDMA code.	5.9
5.2	Comparison Between MDW, MFH And Hadamard Codes.	5.13

LIST OF FIGURES

Figure		Page
1.1	A general Study Model of This Research Work.	1.9
1.2	Chips Spacing.	1.16
1.3	Ideal Rectangular Shaped Weights.	1.16
2.1	Adding a Node.	2.7
2.2	Tap-and-Inserts.	2.9
2.3	Optical CDMA Equipments.	2.11
2.4	Delayed Lines Based Coherent Direct Sequence Optical CDMA [66].	2.13
2.5	Time Spread Optical CDMA.	2.15
2.6	Incoherent spectral intensity encoded optical CDMA system.	2.17
2.7	OSCDMA Transmitter Encoding.	2.18
2.8	The System Architecture of The OSCDMA Network.	2.20
3.1	Scope of Study in OCDMA Code Development.	3.1
3.2	DW Code Encoder/Decoder Using Two Filters and One Filter.	3.8
3.3	General Form of MDW Code Matrix.	3.10
3.4	OCDMA Code Multiplexed into a Common Fiber.	3.15
3.5	Figure 3.5 Encoder Configurations and Encoding Process (Evolution of Spectrum)	3.22
3.6	Decoder Configurations and Decoding Process	3.22
4.1	Thermal-Noise Sources in a Photodetector.	4.9
4.2	Implementation of the Complementary Subtraction Technique.	4.11

4.3	Implementation of the AND Subtraction Technique.	4.13
4.4	Optical CDMA System Architecture Using Complementary Subtraction Technique.	4.16
4.5	The PSD of the Received Signal $r(\nu)$	4.21
4.6	Optical CDMA System Architecture Using AND Subtraction Technique	4.25
4.7	BER Versus Number of Simultaneous Users When $P_{sr} = -10$ dBm.	4.28
4.8	BER versus P_{sr} When Number of Simultaneous Users is 15.	4.29
4.9	Simulation Setup for OCDMA System with AND Subtraction Technique.	4.31
4.10	Simulation Setup for OCDMA System with Complementary Subtraction Technique.	4.31
4.11	BER versus Distance for OCDMA Systems Using AND and Complementary Technique at Different Transmission Rates.	4.33
4.12	Noise Power and Output Power versus Distance for Different Subtraction Technique.	4.34
4.13	BER versus Input Power for Different Subtraction Technique.	4.36
4.14	Noise Power versus Input Power and Output Power.	4.37
4.15	BER versus Bit Rate for Different Subtraction Technique	4.38
5.1	PIIN Noise versus Received Power (P_{sr}).	5.3
5.2	PIIN Noise versus Number of Active User (K).	5.4
5.3	BER Versus Number of Active User By Considering PIIN Noise Only.	5.5
5.4	Shot Noise versus P_{sr} for Various OCDMA Codes.	5.7
5.5	BER versus P_{sr} by Considering Only Shot Noise.	5.8
5.6	BER Versus Effective Power P_{sr} When The Number Of Simultaneous Users is 9, Taking Into Account The Intensity Noise, Shot Noise And Thermal Noise.	5.10

5.7	The Signal and Noise Power in Various OCDMA Code.	5.11
5.8	BER versus Number of Simultaneous Users (K) when $P_{sr} = -10$ dBm.	5.12
5.9	SNR versus Number of Users for MDW, MFH and Hadamard Code at $P_{sr} = -10$ dBm	5.14
5.10	The System Architecture of Optical CDMA Network Under Study Using OptiSystem 3.0	5.15
5.11	Eye Diagram of One of the MDW Channels At 10 Gbps.	5.16
5.12	Eye Diagram of One of the Hadamard Channels At 10 Gbps.	5.17
5.13	Eye Diagram of One of the MFH Channels At 10 Gbps.	5.18
5.14	OCDMA System Using Externally Modulated Technique.	5.20
5.15	OCDMA System Using Directly Modulated Technique.	5.20
5.16	BER versus Distance for Different Modulation Technique at Various Bit Rate.	5.21
5.17	Multiple Source OCDMA System.	5.23
5.18	Single Source OCDMA System.	5.24
5.19	BER versus Distance for OCDMA System Using Different Optical Source.	5.25
5.20	The Variable Weight OCDMA System Architecture.	5.27
5.21	Eye Diagram of the DW-Encoded Channel at 2.5Gbps with BER of 9.65×10^{-4} After 63 km Transmission.	5.28
5.22	Eye Diagram of the MDW-Encoded Channel at 2.5 Gbps with BER of 2.17×10^{-11} After 63 km Transmission.	5.28
5.23	The Multiple Bit Rate OCDMA System Architecture	5.30
5.24	Eye Diagram of the MDW-Encoded Channel 3 at 2.5Gbps with BER of 2.52×10^{-12} After 68 km Transmission.	5.31
5.25	Eye Diagram of the DW Channel 1 at 10Gbps with BER of 2.05×10^{-12} After 52 km Transmission.	5.31
6.1	Point-To-Point System Simulation Layout.	6.3

6.2	BER versus Distance at Different Bit RateUsing DW Codes.	6.6
6.3	Output Power and Noise Power versus Distance at Different Bit Rate.	6.7
6.4	BER versus Input Power for OCDM System at Bit Rate of 2.5 Gbps.	6.8
6.5	Output Power and Noise Power versus Input Power for OCDM system at Bit rate 2.5 Gbps.	6.9
6.6	BER versus Chip Spacing at Bit Rate of 2.5 Gbps.	6.11
6.7	BER versus Bit Rate.	6.12
6.8	Experimental Setup for OCDM System Using DW Code.	6.14
6.9	Spectral Overlapping for The Experimental Codes.	6.15
6.10	Spectrum for Output Encoder Code 1 (011).	6.16
6.11	Spectrum for Output Encoder Code 2 (010).	6.17
6.12	The Combined Spectrum Inside Fiber.	6.17
6.13	Eye Pattern Before Subtraction.	6.18
6.14	Eye Pattern After Subtraction.	6.18
6.15	BER versus Received Power at Bit Rate of 2.5 Gbps.	6.19
6.16	BER versus Bit Rate for Experiment and Simulation.	6.20
6.17	BER versus Received Power at Bit Rate of 622 Mbps.	6.21
6.18	BER versus Received Power for Hadamard and DW Codes at Bit Rate 622 Mbps.	6.23

LIST OF ABBREVIATIONS

BER	-	Bit Error Rate
CD	-	Chromatic Dispersion
CDM	-	Code Division Multiplexing
CDMA	-	Code Division Multiple Access
CIDF	-	Component Iteration Data Flow
CO	-	Central Office
CW	-	Continuous Wave
DFB	-	Distributed Feed Back
DW	-	Double Weight
DWDM	-	Dense Wavelength Division Multiplexing
EDFA	-	Erbium-Doped Fiber Amplifier
ESCON	-	Enterprise Systems Connections
FDDI	-	Fiber Distributed Data Interface
FDMA	-	Frequency Division Multiple Access
FH	-	Frequency-Hopping
FP	-	Fabrey Perrot
FSAN	-	Full Service Access Network
FTTH	-	Fiber to the Home
FWM	-	Four Wave Mixing
GF	-	Galois Field
IP	-	Internet Protocol
ISI	-	Inter Symbol Interference

LAN	-	Local Area Network
LCM	-	Liquid Crystal Modulator
LD	-	Laser Diode
LED	-	Light Emitting Diode
LMDS	-	Local Multipoint Distribution Service
MAI	-	Multiple Access Interference
MAN	-	Metropolitan Area Network
MDW	-	Modified Double Weight
MFH	-	Modified Frequency Hopping
NDSF	-	Non-Dispersion Shifted Fiber
NRZ	-	Non-Return to Zero
OCDM	-	Optical Code Division Multiplexing
OCDMA	-	Optical Code Division Multiple Access
OOC	-	Optical Orthogonal Codes
OOK	-	On/Off Keyed
OSCDMA	-	Optical Spectrum Code Division Multiple Access
OSNR	-	Optical Signal to Noise Ratio
PIIN	-	Phase Induced Intensity Noise
PMD	-	Polarization Mode Dispersion
POP	-	Point of Presence
PRBS	-	Pseudo Random Binary Sequence
PSD	-	Power Spectral Density
QoS	-	Quality of Service
QPSK	-	Quadrature Phase Shift Keying